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PROCEDURES FOR SAMPLING AND MEASURING INDUSTRIAL WASTES

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PROCEDURES FOR SAMPLING AND MEASURING INDUSTRIAL WASTES*

Public Health Service
DIV. OF SANITARY ENGINEERING SERVICES
Reference Room

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Knowledge concerning the character and volumes of industrial wastes is the first requisite in their evaluation. Sampling and measuring constitute an integral and important part in this evaluation. This recalls the maxim "A chain is no stronger than its weakest link." Certainly every one who studies industrial wastes strives to make the accuracy of field observations consistent with laboratory techniques. It is with these thoughts in mind that the following review is offered.

Sampling Procedure

Objectives

An industrial waste sampling program may serve any one of several or a combination of purposes. Because sampling procedures vary with contemplated use of the findings, it is essential that objectives be defined at the outset of the study. Some of the more common objectives are to:

1. Determine quantities of pollutional materials discharged during a 24 hr. day and per unit weight of product.
2. Locate major waste sources within the plant and to permit computing of constituent balances.
3. Explore potential recovery from a given department or unit process, to consider process modification, and to study the economics thereof.
4. Define factors influencing character of wastes from a given department or unit process.
5. Investigate and demonstrate variations in character and concentration of combined wastes.
6. Establish a sound basis for treatment of residual wastes.

Process and Operation

A time should be selected for the study when plant operations are normal. Production should be reported for each day of sampling and its per cent of capacity operation should be indicated. Consideration must be given to periods of maximum waste discharge which may impose short-time but damaging pollutional effect. Intelligent planning requires familiarity with the processes involved and with operation schedules. The sources of major individual wastes should be recognized. Raw materials and finished products, any of which may appear in the waste, should be known. Close attention should be devoted to possible hazards to workmen in manholes and around sewer outfalls and to analysts handling the wastes. Knowledge is necessary of any compounds likely to interfere with the analytical work or of the presence of toxic materials which might inhibit biochemical oxygen demand. Disposition of plant sanitary wastes should be recorded.

Determinations

Having established objectives and with general information regarding the process, the next logical step is to develop the analytical phase. Decision as to determinations will be influenced by anticipated pollutional constituents in the waste and the primary objectives of the program. In considering analytical work, it is advisable to set up minimum requirements beyond which priorities may be fixed for other desirable but not essential tests. Usually available time and funds enter into these deliberations.

Organization of the analytical work should take into consideration subsequent use of the receiving waters. The more common parameters of pollution should always be included. Cognizance should be taken of the fact that new manufacturing processes and complex waste mixtures may produce wastes requiring research on analytical methods. A discussion of such analytical problems is

beyond the purview of this paper.

Sampling Program

The objective of all sampling is to collect a representative portion for analysis, the results of which will portray the true picture of the material sampled. There are many considerations relative to sampling which apply generally and the special problems must be solved individually as they arise.

The approach to industrial waste sampling deviates somewhat from the more or less standard procedures employed in sewage treatment works control. The program for sampling industrial wastes must be tailored to fit the operations of each manufacturing plant and the characteristics of the wastes produced. Even the novice in industrial waste work will recognize the need for special procedures in sampling such wastes as the combined discharge from an integrated steel mill. This discharge will contain floating oil; mill scale, which settles rapidly; and such highly volatile dissolved gases as hydrogen cyanide and hydrogen sulfide. Furthermore, batch dumping of spent acid from discontinuous pickling operations will cause significant variations in pH and iron content.

Examination of an up-to-date sewer map showing sewer locations with respect to manufacturing areas will facilitate the establishing of sampling points and decision as to the number of samples to collect. It is desirable to analyze the major individual wastes within the plant as a check against quantities appearing in the combined discharge. This procedure not only gives a more complete picture but also provides data of maximum value. Corrections are frequently necessary for constituents present in the industrial water supply.

The number of samples must be synchronized with the number and type of determinations and the physical capacity of the analysts. It should be recognized that the rate of performing analytical work varies widely and that over-

loading of the laboratory may result in inferior work. Personnel requirements have been estimated for various analytical programs (1). The chief analyst should collaborate in preparing the sampling schedule, thus assuring a balanced program. The laboratory should be provided samples for exploratory work prior to routine sampling.

The objective of the sampling program will govern the duration of the project and the type of samples to be collected. It is seldom that dependable data can be assured in less than a 5 day study, although not necessarily consecutive days. A two-week period is recommended. The types of liquid samples may be broadly classified into two groups; namely, grab samples and composite samples.

The grab sample serves as a spot check. The analytical results from a grab sample are of limited value but may be useful in investigating abnormal waste characteristics. A series of grab samples is useful in tracing constituent variations. Waste concentrations caused by batch dumping can thus be shown, whereas compositing levels off these peaks. Textile finishing wastes exhibit still another discharge pattern. Such wastes in the first part of the day may have a pH as high as 11.0, followed by a low of 3.5, with a composite pH slightly above neutral. Potential damage from these extremes is completely concealed by the composite. Grab samples are essential for such determinations as dissolved oxygen, chlorine demand, and chlorine residual.

Composite samples show the average conditions and give results which are useful in computing quantities of waste materials discharged per 24-hr. day or per shift. If the rate of flow is constant, the composite is composed of a number of uniform portions collected at frequent regular intervals. However, if the rate of flow varies, as is usually the case, a weighted composite is

collected, in which case the volume of each portion is proportional to the rate of discharge at the time it is collected. If the samples are composited manually, this means instantaneous determination of discharge rate from a flow chart and reference to a previously prepared table or chart giving size of sample portions corresponding to various discharge rates. Composite sampling has the advantage of minimizing analytical work.

Liquid wastes from continuous manufacturing operations are normally composited either over an 8-hr. shift or on a 24-hr. basis. Occasionally samples composited over 4-hr. periods may be representative. Many processes are sufficiently uniform to give a fairly constant rate of waste discharge. However, plant and equipment clean-up is commonly concentrated in the day shift. It is also possible that a minimum operating crew on the graveyard shift might experience more irregularities that would influence the character and volume of the wastes discharged. In case of doubt, each shift should be sampled separately or the composite should be over 24 hr. The only truly representative sample is the weighted 24-hr. composite. It is advisable to divide an industrial waste survey into two phases in order that experience from the first phase may be applied to improve the second and the project as a whole.

Manual Sampling

Manual collection of samples is practical and reasonable for exploratory work and for short-time surveys. The practice should not be thought of as reversion to horse-and-buggy days. It gives needed flexibility to the program and provides a record of unusual occurrences which might affect the samples. In some cases, the sampling can be performed with approximately the same man-hours as required for installation and checking of an automatic sampling device. Manual sampling provides basic information useful in preparing specifi-

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cations for automatic sampling equipment, and continuous recording instruments, which may later be recommended.

Except where the distance between sampling points is too great, one man per shift can take all samples and record essential data. The interval between collection of composite sample portions may be as short as 3-min. for an intensive study. The sampling interval should not be greater than 30-min. and a 15-min. interval may be essential. In general, the shorter the time interval the more truly representative will be the sample.

Scientific aides from the research or engineering departments usually possess the desired qualifications for samplers. Regardless of their background, it is imperative that samplers be given explicit instructions. These should preferably be in writing for convenient reference. The instructions should be systematic, concise, and complete. Misunderstanding can be minimized and a higher level of performance can be achieved by demonstrating, to the sampling team collectively, the techniques and procedures to be employed.

It is advisable to acquaint the sampling team with the over-all objective of the project as a means of creating job interest. Each sampler should be made to realize the importance of collecting a representative sample. Insofar as possible, laboratory techniques are projected into the field in the collection of samples. For example, the use of protected graduates in measuring the portions composited produces a desirable psychological effect on the sampler and creates in him an appreciation of the need for accuracy. The sampling team should be briefed on personal safety measures, especially the hazards associated with entering sewer manholes. A two-man team is customary when entering manholes.

Sampling Equipment

Manual sampling of industrial wastes can usually be satisfactorily accom-

plished with simple collecting devices. When the wastes are homogeneous, a stainless steel dipper mounted on a rigid, light-weight rod may prove satisfactory. It should be cylindrical in shape with wide-mouth opening (2 inches minimum) to allow ready ingress and egress of suspended solids. The sampling container should be sufficiently large to give an adequate quantity for the largest portion composited.

It is occasionally desired to explore the characteristics of wastes at different depths in large sewers. This can be accomplished by lowering a weighted bottle to the desired depth before removing the stopper and then holding it in place until the bubbles cease to rise. There will be very little waste displaced from the full bottle while it is being drawn to the surface. When visibility is poor, an alternative system is to fix the suction of a pump at the point in the flowing waste where the sample is to be collected.

When stratification is suspected, it is desirable to collect a sample throughout the full depth (cross-sectional sampling). Various samplers have been devised for this purpose. In general, this type sampler consists of a cylinder open at each end with provision for automatically stoppering the lower end when the bottom of the sewer is reached. The Shell Oil Company Standardization Committee (2) has developed an ingenious sampler of this type, (see Figure 1), consisting of a graduated plastic tube, which moves freely inside an aluminum guide. In sampling position, the tube is raised and set on the trigger support. The sampler is then lowered into the waste until the trigger release touches bottom. This impact trips the trigger, allowing the tube to drop through the waste and to make a seal with the rubber stopper. This device is recommended for sampling where the depth of flow is less than 1 ft.

The volume of an industrial waste sample required for a fairly complete analysis will normally range between 2 and 3 liters. The quantity submitted to

the laboratory should include a surplus for check analyses. When the waste contains settleable solids, the bottles should be large enough to allow some air space which facilitates mixing in the laboratory. The number of sample bottles must be sufficient to permit holding each sample until the analytical work has been completed and checked.

The container used for compositing may well be a 3 or 5 gal. glass carboy. Unless the individual portions are of interest to show the pattern of concentration fluctuations, it is advisable to composite each portion as collected. The whole procedure is simplified by keeping composite bottles, in sheltered areas, at the respective sampling points. This practice also precludes introducing portions taken from one sampling point into the composite from another, which is always possible when all composite bottles are arrayed at a common point.

There are certain minimum requirements with respect to sampling equipment which should be observed. For example, some solvents in wastes will attack rubber stoppers thereby contaminating the samples. Another is the influence of corrosion of iron caps on an iron determination. Sample bottles with ground glass stoppers should be specified. In addition to glassware, sampling equipment should include such miscellaneous items as: a log board, cross-section paper, flashlight with extra batteries, thermometers, folding rule, tarpaulin, funnels, jack knife, and hatchet and nails.

Sampling Considerations

Procedures to follow in sampling will always require exercise of judgement--ability which develops with experience. Each sampling point will warrant attention commensurate with its complexity. There are, however, basic ideas which apply generally to sampling technique. Consideration of the following

items usually enters into the organization of each sampling program:

1. Preferred sampling point. The sample should be collected where the wastes are homogeneous. These conditions usually exist below a weir, Parshall flume, or hydraulic jump. Care should be exercised in sampling below a weir. Serious sampling errors can occur from deposition of settleable solids in the pool upstream from the weir and from the accumulation of floating oil or grease immediately downstream.

2. Sampling sewers and deep, narrow channels. Avoid skimming the water surface and dragging the channel bottom. A sampling point one-third the water depth from the bottom is suggested.

3. Sampling discharge through large conduits. In wide channels, the point of collection should be rotated across the channel. In deep conduits, the most satisfactory depth to sample might well be determined by experiment.

4. Velocity distribution. Most sampling is done at sewer outfalls, sewer manholes, or in conduits flowing partly full. These represent open-channel conditions. A vertical velocity curve generally shows the maximum velocity to occur near the center of the channel and two-tenths or three-tenths the depth below the water surface. The minimum velocity occurs along the walls and bottom. At the point where the sample is collected, the velocity should be sufficient to prevent deposition of solids.

5. Induced turbulence. Agitation in measuring, collection, and handling of the sample portions may liberate dissolved gases through aeration. Field determinations should be made when such losses are suspected.

6. Sampling from deep sewer manholes. The sampling mechanism must be kept under control at all times to prevent contamination of the sample with extraneous material. Adequate lighting must be provided for routine sampling and to facilitate inspection.

7. Weather conditions. Outside sampling is most satisfactory during mild weather, at which time there is a minimum of steam emanating from sewer manholes. A portable blower is useful in allieviating the steam nuisance. Precipitation is recorded and proper corrections are made.

8. Proportionate sampling errors. Serious errors may be introduced in the suspended solids concentration during proportioning. This can easily result from failure to keep the sample well mixed while pouring into the measuring receptacle. It may also result from virtual decantation, by delaying measurement, in striving for volume accuracy. Rapid measurement of the individual volumes is essential. Samplers should be alerted to these potential errors.

9. Sampling for oil. Collection of a representative sample of waste water containing oil is most difficult. Although each sampling job presents its own peculiar difficulties, there are basic considerations which are generally applicable to sampling for oil.

Petroleum oils are relatively insoluble in water, accordingly mixtures of water and oil usually constitute a heterogeneous mixture. Even though the oil may be dispersed in small globules, some oil will adhere to the sampling device each time a portion is collected. This requires special provision for compositing.

It is practically impossible to obtain a representative sample when there is free floating oil. However, it is possible to collect composite samples from a heterogeneous mixture. Because it is not possible to take aliquot portions of a sample for analysis, it is imperative that the entire sample be taken for analysis.

One system that has been used is to insert two glass tubes through a rubber stopper in a glass sample bottle. Each portion is taken directly into the bottle through the inlet glass tube which extends to a point near the bottom of the bottle. The second glass tube, which serves as an air release, is

raised a predetermined amount each time a portion is to be added. Oil adhering to the inlet tube and the inside of the bottle is extracted by the solvent used in analysis and is included in the sample.

The American Petroleum Institute Committee on Disposal of Refinery Wastes has long been confronted with the problem of sampling for oil in refinery effluents. The best information on this subject available to the Committee is summarized in a manual entitled "Disposal of Refinery Wastes" (3). The reader is referred to Section I of this manual for further information on sampling for oil.

10. Sampling for acidity. Irregular discharge of acid wastes, such as spent pickle liquor, makes it desirable to determine the pH of each portion collected. Hydrogen ion concentration may be determined either colorimetrically or electrometrically by means of the hydrogen electrode and the potentiometer. This determination can usually be made in the field but, if not practicable, the individual portions should be transported to the laboratory and the pH of each determined before compositing.

11. Protection of sampling mechanism. The dipper or container used for sampling should be treated as a laboratory item. When not being used, it should be kept off the ground and upside down. A separate sampling container should be provided at each sampling point. Samplers and sampling containers should be washed and clean before each sampling period is started and bottles should be protected by stoppers.

12. Identification of sample. A standard identification card should be prepared by the sampler for each sample and attached to the bottle before it is moved from the sampling point. This card gives date and time of collection, origin of sample, method of collection, name of sampler, and pertinent remarks.

Sample Preservation

The heterogeneous character of most trade wastes renders them relatively unstable. The rate of change is influenced by temperature, pH, concentration, bacterial action, and inter-molecular reactions. The problems of preservation are complicated by the fact that treatment to fix one constituent may liberate another. This means multiple sampling at each point for stabilization by different methods.

Specifications for stabilizing a sample must satisfy several requirements. First, are the steps to be taken during the period the sample is being composited. Next, is the time factor and conditions while in transit to the laboratory and temporary storage while being analyzed. Finally, consideration must be given to the effect which the treatment for preservation may have on the analytical procedures to follow.

Prompt analysis is the most positive assurance against error from sample deterioration, but this does not satisfy requirements of the composite, portions of which may be stored for as long as 24 hr. It is imperative that stabilization be attempted. Procedures being used to preserve industrial waste samples include refrigeration, acidification, alkalinization (occasionally causticization), and chemical treatment. Chemical treatment stabilizes either by direct chemical reaction, as zinc acetate to fix sulfides, or through inhibition of biological activity, for which copper sulfate to hold phenol is typical. Laboratory work with wastes containing hydrogen cyanide indicate causticization (pH 10 to 11) to be essential for stability.

Refrigeration is the most common method for sample preservation. Those who have worked with highly organic wastes such as those from the food processing industry, will attest to their rapid decomposition at room temperature. Temperature control at approximately 4° C. retards bacterial action and sup-

presses volatilization of dissolved gases. Refrigeration is particularly important for the biochemical oxygen demand determination, for which pre-chemical treatment is prohibited.

Published methods for "fixing" water-borne industrial wastes have been summarized by Hauck (4). This summary indicates the need for further research in this field. A subcommittee of Committee D19 (on Industrial Water) of the A.S.T.M., has been organized to study and develop dependable procedures for preservation of various types of industrial waste samples.

The procedure used to preserve unstable constituents in a sample should be described in discussing the analytical results. In the absence of a proven method for preserving unstable constituents in a sample, the probable error should be designated in reporting the analytical data.

Mechanical Sampling

Modern industry with its highly trained engineers and technologists is a Mecca for mechanical and electrical equipment. Mechanical sampling of liquid industrial wastes is, accordingly, a foregone conclusion for permanent installations. Industrial technicians not only possess the "know-how" to develop automatic sampling equipment, but they are also skilled in maintenance. Proof of this assertion rests in the published descriptions of ingenious sampling devices recently developed by representatives of industry, (5)(6)(7). The samplers described in these references were developed for sampling liquid wastes relatively free from suspended solids. Modifications in the design of these samplers would be expected when applied to other types of wastes.

Mechanical sampling of liquid wastes is by no means a new idea. In fact, various designs have been employed for years in sampling domestic sewage. Some of those earlier devices have been perfected and are available commercially for sampling trade wastes.

Correctly designed, properly installed, and skillfully operated mechanical equipment for sampling industrial wastes accomplishes four purposes, namely:

1. Eliminates inevitable errors due to the human element in manual sampling.

2. Reduces to a minimum costly personnel requirements.

3. Eliminates a routine task which can devolve into an irksome chore.

4. Provides a more frequent sample than is practicable by manual sampling.

Some automatic samplers are designed to collect weighted composites; others composite uniform portions at regular intervals without reference to flow. Those samplers collecting portions proportional to the flow accomplish this in two ways. One type takes a portion at regular intervals, the size of each portion being directly proportional to the discharge at the time of collection. The other type is actuated by a flow meter transmitter or totalizer, or employs a proportioneer in conjunction with a primary measuring element, which causes a portion of uniform size to be collected each time a fixed volume of waste is discharged. Further discussion is confined to proportionate samplers.

The first type of proportional sampler is illustrated in Figure 2. The principal feature is a metal disk with a narrow flat scoop attached, which is rotated inside a weir box by a small motor. The scoop is so designed and mounted that the sample taken each time the disk revolves is directly proportional to the flow over the weir at that time. Scoops are provided with two size slot openings, one 3/8 in. and the other with 3/4 in. width of opening. The 3/4 in. scoop is intended for wastes having large solids that might lodge in the more narrow scoop. The sampler is available with or without time-clock control. The time-clock controlled machine is normally used where the flow is steady and sampling once every 15 min. is satisfactory. The depth in the scoop of the average size sample gives directly the average head on the weir

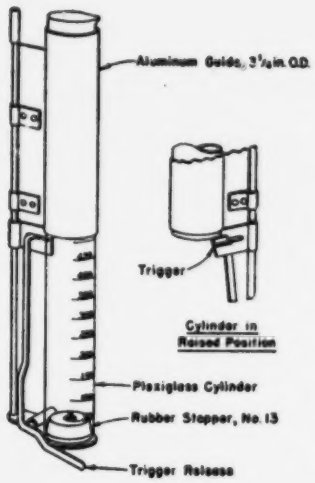

Fig. 1. Manual sampler for collection of a vertical cylindrical sample. Courtesy Shell Oil Company.

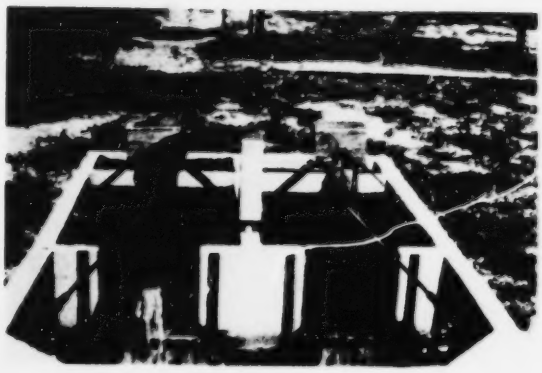

Fig. 2. Two proportional samplers operating in parallel. Sampler on the right is just starting to take a sample while the other sampler is just finishing the discharge of a sample to the gallon jug in the foreground. Coursesy H. A. Trebler.

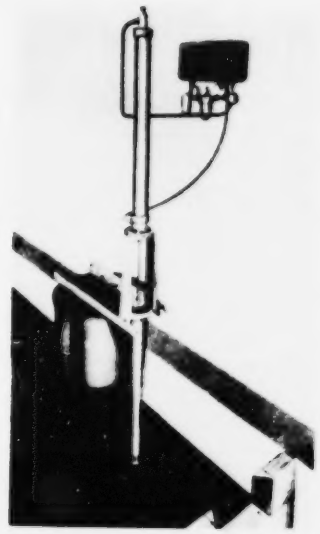

Fig. 3. Liquid waste proportional sampler and electric timer. Sample portions are deposited in a graduated container from which a direct reading of the total flow for the sampling period is obtained. Courtesy DeZurick Shower Company.

during the sampling period.

Another design employing the same principle is shown in Figure 3. This sampler, also mounted back of a weir, takes a series of samples, each proportional to the flow at the time collected. The sampler properconsists of a vertical tube with a specially curved plunger on the inside. The plunger is raised and lowered by means of a piston operating within an air cylinder located immediately above. The operating cycle is controlled by an electric timer, which actuates a solenoid valve at fixed intervals, causing the plunger to withdraw a sample of the flowing liquid and to deposit it in a graduated container. The waste enters the tube through radial slots at the lower end when the plunger is in the down position. The shape of the plunger is calculated to make the volume of waste entering the tube proportional to flow over the weir. The radial slots must be sufficiently large to prevent straining suspended solids from the waste being sampled.

Figure 4 is typical of the second type of proportional sampler. In this unit, the waste flows by gravity or is pumped to a small reservoir inside the sampler body. Discharge from this reservoir is by gravity over a weir. The sampling mechanism dips a fixed size (25 ml.) sample from the liquid just before it flows over the weir and deposits it in a 1-gal. bottle located in a refrigerated compartment. A small sampler motor causes the dipper to revolve intermittently and at varying intervals. The rate of sampling can be adjusted between 3 and 20 samples per hour. The frequency of sampling can be regulated by the transmitter of an electrically operated totalizing flow meter or by connection to the totalizing meter itself. Proportional sampling can also be accomplished by means of a float-controlled timer, which intermittently closes an electric circuit between it and the sampler motor. An installation

of this mechanical sampler, with pump and float-controlled timer, is shown in Figure 5.

As electricity is not always available at sampling points, there is occasional need for portable sampling equipment. Figure 6 shows a portable sampler operated by a car heater motor, which uses a storage battery for power. A time-clock fixes the sampling interval at 15 min. and each portion is proportional to the flow at the time it is collected.

Although mechanical sampling would appear to offer numerous advantages over manual sampling, it should be realized that automatic samplers also have limitations. Like all mechanical equipment, they require maintenance. Close attention is necessary when the waste contains heterogeneous suspended solids, some of large diameter. Mechanical samplers are restricted as to diameter of feed pipe, width of scoop, and size of slots. Individual portions must either be small or exessively large receivers are needed. Daily cleaning of all parts in contact with the waste is mandatory. Another limitation is the fixed sampling point. The manual sampler can rotate sampling points to cover the entire cross-section of flow if this proves desirable. From the foregoing, it will be apparent that a mechanical sampling installation should be checked by parallel manual sampling prior to acceptance.

A complete discussion of mechanical sampling equipment is beyond the scope of this paper. This review is intended to acquaint the reader with representative equipment that is available. Those interested in exploring the subject further are referred for detail to manufacturers catalogs, to published articles describing devices developed by industry, and to other publications dealing more specifically with automatic samplers (4)(8).

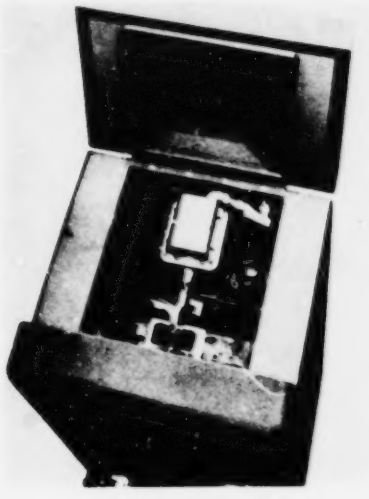

Fig. 4. Top view of automatic sampler showing principal parts. A constant size portion is dipped from the waste reservoir at intervals which vary with the flow. Courtesy Chicago Pump Company.

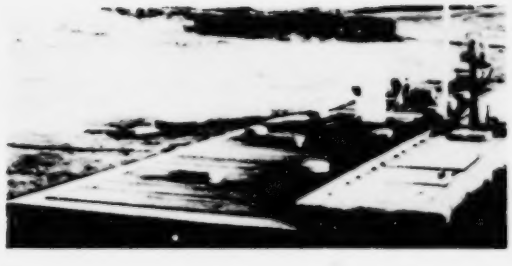

Fig. 5. Portable automatic sampler showing pump, sampler, and float-controlled timer. Float actuating timer (pedestal mounted) is installed at inlet end of covered longitudinal clarifier.

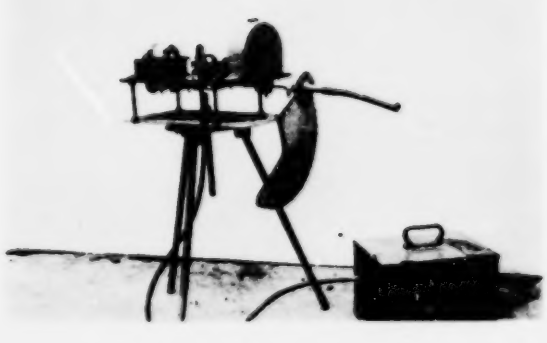

Fig. 6. Portable proportional sampler showing principal components. From left to right are the motor, clock, dipper, and storage battery. Courtesy Michigan Water Resources Commission.

Measuring Procedure

The network of sewers and piping in a modern industry presents problems in flow measurement that tax the ingenuity of the most competent hydraulician. Although every conceivable method for measuring liquids eventually receives consideration, there are some procedures which are used much more frequently than others. Because the great majority of industrial waste flow measurements are made at sewer outfalls or in sewers flowing partly full, this discussion is devoted primarily to open-channel flow.

Selection of Method

Consideration must be given to the reliability and accuracy of the various methods for measuring liquid wastes which are applicable to the specific field conditions. The approach to this problem will be influenced in some measure by the degree of permanency. Testing facilities frequently involve a compromise between cost and acceptable results, whereas greater refinements may be justified for permanent installations. Final decision as to the preferred method for a given installation will be based largely on the objectives of the project as outlined in an earlier section of this paper.

There are a number of excellent references on the subject of hydraulics (9)(10)(11)(12). Review of such reference material is encouraged in connection with design of flow measuring systems. This procedure, for those not routinely engaged in this phase of engineering, will go far in improving the quality of flow data obtained. The discussion which follows, though elementary in nature, presupposes some knowledge of hydraulics.

Flow Estimates

The first consideration in design of a hydraulic structure for measuring liquid wastes is to estimate the maximum, minimum, and average flows for which accurate measure is desired. Occasionally, water consumption correlated with

plant operations will suffice for this purpose. In most cases, it will be preferable to make "on-the-spot" checks. Any one of the following methods may prove useful.

1. Surface floats. Any object that floats with its center of gravity near the surface of the water will register the velocity of the surface filaments. The mean velocity in the vertical is obtained by multiplying the surface velocity by the coefficient 0.85 (9). Application of the mean velocity to the cross-sectional area of flow should give a conservative value for discharge.

2. Volumetric measurements. It is often possible to time with a stopwatch the filling of a container of known volume. Similarly, an existing flow-through basin may occasionally be used by temporarily closing the outlet and timing the rise, making certain that free discharge at the inlet continues during the test. A series of readings should establish the pattern of flow and indicate the capacity required of a continuous flow measuring instrument.

3. Critical depth at outfall. Critical depth is the depth at which, for a given total head $D + \frac{V^2}{2g}$, the discharge is a maximum. This refers to water flowing in an open channel at a depth D and with a mean velocity V. The expression $\frac{V^2}{2g}$ (velocity head) represents the kinetic energy of the flowing water.

Applied to a sewer outfall with free discharge, critical depth occurs at the end of the sewer. Hinds (13) has shown that discharge from a rectangular sewer can readily be determined by measuring the critical depth and the width of the channel and substituting these values in

$\frac{Q^2}{g} = b^2 d_c^3$ in which Q = flow in cubic feet per second;
g = gravity, or 32.16 ft. per sec. per sec;
b = channel width, in feet; and
d_c = critical depth, in feet.

4. Pitot tube measurements. A pitot tube can be used to measure velocity head where the sewer is readily accessible and the velocity is 3 ft. per sec. or greater. The head, h, is read and the velocity determined from

$$H = \frac{v^2}{2g}$$

The mean velocity is determined by plotting the velocity curves from traverses in two or more vertical planes. An alternative procedure for determining the mean velocity is to take the average of velocities at the 0.2 and the 0.8 depths. Discharge is computed using the mean velocity and the measured cross-section of flow.

5. Sewer size and slope. In congested areas, it is not uncommon to experience the need for information on sewer discharge under conditions which make installation of accurate flow measuring devices impracticable. Usually it is possible to install a liquid level recorder in a manhole downstream from an unobstructed straight section of sewer, thus providing a continuous record of the depth of flow. Additional field data required include sewer size and slope and an estimated coefficient of roughness. Erosion of the sewer invert should be checked. It is always advisable to measure the sewer size when investigating roughness of the surface and to determine the invert slope by means of an engineers' level.

Because the formula for open-channel flow is quite complicated, it is advisable to refer to prepared nomographs to aid in its solution (14). Discharge through sewers flowing partly full is determined by first solving for full-flow conditions and then converting to partial-flow conditions. An estimate of total flow can be made by applying the mean of discharge values corresponding to a representative number of flow depths.

Sharp-Crested Weirs

Weirs, because of their simplicity and economy of construction, have been

widely used in measuring industrial wastes. The rectangular, 90° triangular, and specially designed weirs offer means of accurately measuring flow, provided certain precautions are taken.

1. Rectangular weirs. Rectangular weirs may be suppressed, single-end contracted, or double-end contracted. Preference is given to the suppressed type because of the absence of any uncertainty due to the effect of end contractions (see Figures 7 and 8). Russell (10) recommends close adherence to the following conditions in design of either the suppressed of the contracted weir:

a The crest must be sharp-edged and horizontal. The crest length should be greater than three times the head, especially for a contracted weir.

b The height of the crest above the bottom of the channel should be sufficient to reduce the velocity of approach to a negligible value. In a suppressed weir, this will require that the crest height be equal to or greater than 5H. For the contracted weir, the cross-sectional area of the channel should be equal to or greater than 6bH (b = length of crest). The crest height should always be sufficient to give complete contraction on the under side of the nappe; all investigators insist that the crest height be at least 2H, and preferably 3H.

c End contractions should be made complete by observing clearance of 3H between the ends of the weir and the sides of the channel.

d Provision must be made at the ends of the weir for the free admission of air to the space beneath the nappe. The existence of a partial vacuum here causes a depression of the nappe and increases the discharge.

e The head must be sufficient to prevent the nappe from clinging

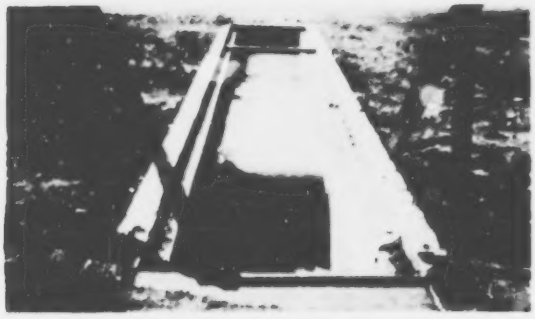

Fig. 7. Sharp crested suppressed weir installed in a concrete flume. Weir crest length = 32 inches.

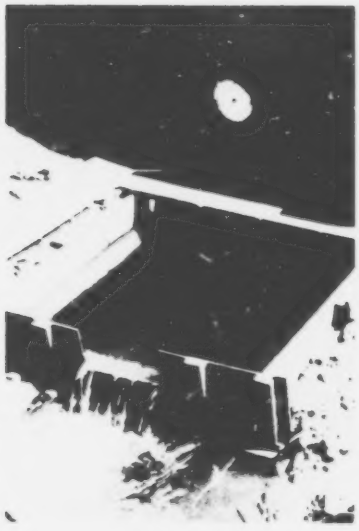

Fig. 8. Sharp crested weir with end contractions. Weir crest length = 18 inches. Liquid level recorded in background.

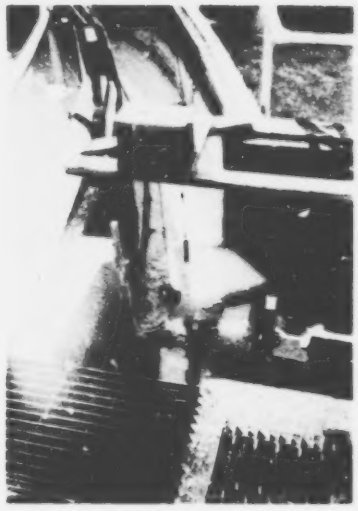

Fig. 9. Typical liquid level recorder which maintains a continuous record of the head on the weir.

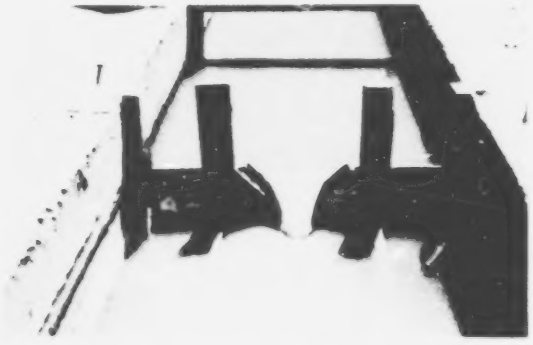

Fig. 10. Temporary 90° V-notch weir using tongue-and-groove lumber as backing for weir plate.

to the front face of the weir.

f The plane of the weir's upstream face must be vertical and smooth. Inclination upstream reduces and a downstream inclination increases the discharge.

g Head measurements should be made at least 6 ft. upstream from the crest, above the effect of the surface curve. There are several types of liquid level recorders that provide a continuous record of the head on the weir (Figure 9). The recorder float should be installed in a stilling well adjacent to and communicating with the channel.

h When a weir box is constructed, it should be long enough to allow the flow to become steady and free from large eddies before reaching the weir crest. Baffles or a slat grid are usually necessary, at the head of the channel, to quiet the water. Best results are obtained by placing wide slats close together with their faces parallel to the flow.

2. Triangular weir. The notch in the triangular weir is usually 90°, but may be 60°. In either case, both sides are equally inclined from the vertical. Formulas for triangular weirs do not take into consideration the velocity of approach. However, if the sides and bottom of the channel are far enough from the notch to give complete contraction, the velocity of approach must necessarily be low (see Figures 10 and 11).

The V-notch weir is preferred over other weirs for measuring discharges of less than 1 cu. ft. per sec. It is believed to be comparable in accuracy with other weirs for measuring discharges between 1 and 10 cu. ft. per sec. It is particularly adapted to measuring fluctuating flows up to 10 cu. ft. per sec. and is accurate for low flows.

3. Cipolletti weir. The notch of the Cipolletti weir is trapezoidal, with the side slopes having an inclination of 1 horizontal to 4 vertical (Figure 12).

The objective in this design was to offset the effect of end contractions, thereby eliminating this correction. Accordingly, discharge through the Cipolletti weir is equivalent to discharge over a suppressed weir of the same crest length. This weir is convenient for use in installations where the heads are highly variable. The formula proposed by Cipolletti for this type weir is:

$$Q = 3.367\ bH^{3/2}$$

4. Choice of formula. The selection of a formula for a given set of conditions is largely a matter of judgment. It is not possible to state that a certain formula is superior to others for general use. Because all weir formulas have been developed empirically, the proportions and velocity of approach for the particular weir installation should be studied and the formula used which was derived under similar condi ons. When field conditions allow some latitude in design, it is prudent to closely duplicate the weir and conditions used by any one investigator and then to use his formula to compute the discharge.

In the use of rectangular weir formulas (such as those of Francis, Bazin, and King), it must be remembered that they apply to suppressed (standard) weirs. If there are end contractions, it is necessary to determine the effective weir length. The effect of end contractions on flow was studied by Francis, who recommended deducting 0.1 H, for each end contraction, from the measured weir length to give effective weir length. The Francis correction is an approximation and its use should be confined to weirs with crest length greater than 3H. Cone (11) has developed a formula for the flow of water through rectangular sharp-crested weirs which takes into consideration complete end contractions. With the exception of the Cone formula, discharge computations for rectangular weirs with end contractions are based on effective length.

5. Limitations. Field conditions frequently do not conform to weir specifications. Head required to control velocity of approach is a common deterrent

to their use. Available space is occasionally insufficient to give complete contractions. Deviations from standard design may give rise to substantial errors in flow measurements unless the modified weir can be calibrated by another more accurate method.

The pool upstream from the weir invites sedimentation, which in turn increases velocity of approach. Under extreme conditions, settleable solids may soon fill a weir box to the crest level. Design of a permanent installation should include a sluice gate for routine flushing of solids from back of the weir.

Weirs are occasionally constructed in sewer manholes and in other inaccessible locations. They are used as an expedient in temporary installations under most adverse conditions. The results of necessarily rough measurement should not detract from potentially high accuracy with correctly designed and properly installed weirs. When not adhering to recommended procedure, the deviations should be described together with their probable effect on the measurements.

Parshall Flume

The Parshall flume was originally developed for measuring water flowing in irrigation channels (15). Its principal virtue, for this application, of being self-cleaning is equally applicable to liquid wastes containing settleable solids. It has been used in sizes ranging in crest length from 3 in. to 50 ft. and for discharges up to 3,000 cu. ft. per sec. Considerable interest has been shown in the Parshall flume for measuring liquid industrial wastes, especially for permanent installations.

This is an empirically rated measuring device. The flume is an open constricted channel, in which the differences in elevation of waste flowing through are accurately translated into rate of flow. It consists of an entrance section with converging vertical walls and level floor, a throat section with parallel

walls and floor declining downstream, and an exit section with diverging vertical walls and floor inclining downstream.

If backwater from the lower channel causes a hydraulic jump, the flow is referred to as submerged. The ratio of submergence is obtained by dividing the downstream head on the crest by the upstream head. The Parshall flume can withstand a relatively high degree of submergence without reduction in the rate of flow. Good design will hold submergence to less than 0.5 for a flume with a throat 6 in. wide, and for wider throats up to 3 ft. the ratio of submergence should not exceed 0.7.

The flume can be constructed of sheet metal (Figure 13), of concrete (Figure 14), or of wood. Satisfactory operation requires setting the crest at the correct elevation with reference to the bed of the channel. If the slope of the channel is slight, care should be taken to install the crest at an elevation which, if possible, will preclude submergence that will exceed the limits of free flow.

The most significant advantages of the Parshall flume are extremely low head requirements, very little effect from velocity of approach, self-cleaning property, wide variations in capacity, reasonable and dependable accuracy, and no moving parts. The only apparent disadvantage is the slightly higher cost as compared with weir construction.

Current Meter

The current meter is useful in measuring flow through large sewers where other methods may prove expensive or impracticable. However, the presence of rags, fiber, and slimes may impair the accuracy of the velocity readings. The meter can be damaged if used in corrosive waters.

Flow through Pipes

Measurement of waste flow in pipes under pressure can be accomplished by

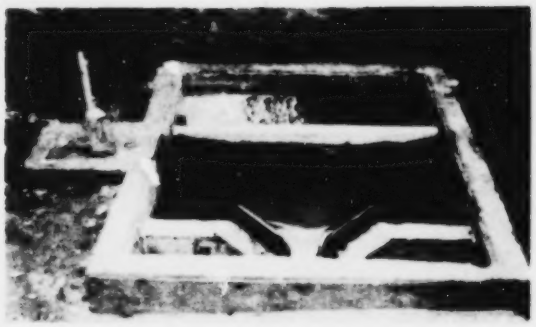

Fig. 11. Permanent 90° V-notch weir installation, outside dimensions 6'-6" X 8'. Baffle contains 4 rows of 1 1/2" pipe spaced 6" c. to c., 28 openings.

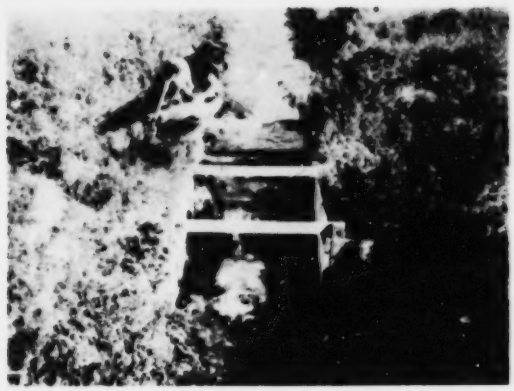

Fig. 12. Cipolletti weir with 18 inch weir crest length. Courtesy Geneva Steel Company.

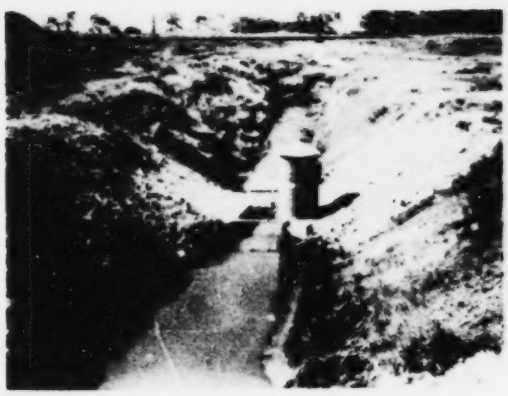

Fig. 13. Parshall flume constructed of steel to permit moving to other locations. This flume has a 3 foot throat. Cylindrical housing is for the water-level recorder. Courtesy Geneva Steel Company.

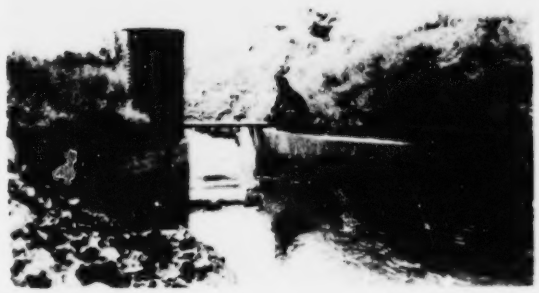

Fig. 14. Permanent installation of a Parshall flume measuring total discharge from an industry. This flume has a 5 foot throat. Courtesy Geneva Steel Company.

any one of several methods. The Venturi meter is particularly well adapted to most industrial wastes. Pipe orifices are dependable for wastes relatively free from settleable solids. Both of these flow measuring devices, with their applications and limitations, have been described in some detail by Hite (16).

Radioactive Tracers

Recent experimental work with radioactive isotopes in flow tests has attracted considerable interest (17). The advantages cited for this new type of tracer are:

1. Radioactive compounds emit distinctive rays that may be positively identified, regardless of the chemical and physical composition of their solvents.

2. Identification of such radiation is easily, quickly, and accurately accomplished.

3. The concentrations of radioactive material required for identification are much smaller than those required by chemical methods (dye or salt).

Although this method appears to possess unusual possibilities, its application must necessarily remain in the hands of the specialist. It will be interesting to see how far this new development will project itself into the broad field of hydraulics.

Industrial Waste Record

Industry should maintain a permanent continuous record of the character and volume of liquid wastes discharged to a natural water course or to a municipal sewerage system. Certainly no industry could remain in business long without accurate knowledge of raw materials and their adherence to rigid specifications. Is there any valid reason why an accurate record of liquid wastes should not be maintained? Numerous cases can be cited where waste records have paid dividends through detection of leaks and spills. Such data have intrinsic value in satisfying a suspicious public rapidly becoming allergic to stream pollution. There is need for more data on unit losses for various types of

industry. But above all is the dire need for continuous records of industrial effluents in the development of an equitable water-use program.

Acknowledgement

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